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A PRACTICAL TREATISE

ON

Friction of Air in Mines.

BY THE LATE

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England.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
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1875.

PREFACE.

THIS essay by the late J. J. ATKINSON, was prepared for the Manchester Geological Society. The recognized value of the paper led to its publication in England in such form as to satisfy the wide demand for so thoroughly practical a treatise.

It was first republished in this country in VAN NOSTRAND'S MAGAZINE, and by reason of a demand for this special subject, it was considered advisable to give it the compact form of the Science series.

WE would call attention of the reader to another work by the same author, also published in this series, on "The Gases Met with in Coal Mines."

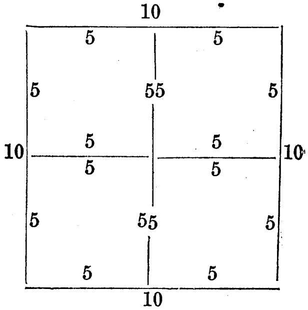
Friction of Air in Mines.

The amount of friction is reckoned as estimated by the amount of the pressure or force required to overcome it.

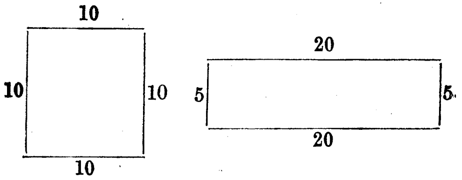
Numerous experiments have been made to find out the laws that govern the friction of air and gases, both in pipes having a uniform section, and, to a less extent, in the irregular air-ways of mines. By these experiments, the following laws have been found to hold good in practice:

The pressure required to overcome the friction of air increases and decreases in exactly the same proportion that the area or extent of the rubbing surface exposed to the air increases or decreases; so that when the velocity of the air, and the sectional area of the air-way, remain the same, the pressure required to overcome the friction is proportional to the area or extent of the rubbing surface exposed to it; and hence, if we double or treble the extent of the rubbing surface, we also double or treble the friction, or, what is the same, the force or pressure required to overcome it. The rubbing surface, of course, depends upon the circumference or perimeter of the air-way, and upon its length. The rubbing surface is found by multiplying the perimeter by the length of the air-way, where it has a uniform section. A circular pipe or air-way offers less rubbing surface, for the same length, than any other form or shape of air-way of equal sectional area; because the circumference of a circle is less, in proportion to its area, than the perimeter or any other figure is to its area. A circle whose area is 1 has a circumference of 3.545, or rather more than 3½; the perimeter of a square is 4, when its area is 1; so that about 7 yards of square pipe would offer the same resistance as 8 yards of round pipe, having an equal size or area of section, when the same quantity of air passes through them in a given time.

It is true that the friction of air or gas, in passing through the same pipe or air-way, varies in just the same degree that the density of the air or gas may vary; but in air-ways in coal mines the air has always nearly one and the same density, and it is only in particular calculations that it becomes requisite to notice its changes of density, in reference at least to this part of the general subject, since they are so small in amount. This is the case as regards friction, but the effects of variations in the density of the air circulating in mines are more sensible in producing pressure, operating either in favor of or against the ventilating pressure, in rise or dip workings; but these effects belong more especially to another part of the subject. In an air-way 5 feet square, the perimeter of a section is 4 × 5 = 20 feet; and if it is 1,000 long, the rubbing surface is 20 × 1,000 = 20,000 square feet. In an air-way 10 feet square, the perimeter of the section is 4 × 10 = 40 feet; and if it was 1,000 long, the rubbing surface would be 40 × 1,000 = 40,000 feet; so that, on comparing the two cases, it will be apparent that for four times the area there is only two times the extent of rubbing surface. If such an air-way as that last mentioned (10 feet square, and having a rubbing surface of 40,000 square feet for every 1,000 feet in length) were divided into four equal-sized square air-ways, the rubbing surface exposed to the moving air would be exactly double by the division; and there would be 20 feet of perimeter for each of the four air-ways, or 80 feet on the whole; so that for a length of 1,000 feet the rubbing surface for the four small air-ways would be 80,000 square feet, or exactly

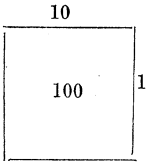


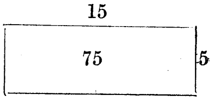
twice as great as that for the one large air-way, although the united areas of the smaller air-ways would be exactly equal to that of the single large one. In one case there would be a single air-way 100 feet in area, and in the other four smaller air-ways, each 25 feet area; but the rubbing surface, and therefore the friction and the pressure required to overcome it for the same gross quantity of air, would be twice as great in the four small as in the one large air-way having the same area. And from this fact we learn that one large air-way is preferable to a number of smaller ones, even if they together make up the same sectional area or size. In practice it often happens, however, that a number of small air-ways can be made and maintained at less cost than one large air-way presenting an equal sectional area; and, in such cases, a few extra air-ways of small area may more than compensate in utility and make up in cost for the absence of one extra-sized air-way; and hence the futility of insisting upon the sectional area of air-ways in mines being of any particular amount, without specifying their number, beyond requiring that one at least in each split be large enough to admit of persons travelling in it. The same principle may be illustrated by taking two air-ways of equal size or sectional area, but having different forms or shapes of section; supposing one of them to be 10 feet high and 10 feet wide, its size or area of section would be 10 × 10 = 100 feet; and supposing the other air-way to be 20 feet wide, but only 5 feet high, the area would be the same (or 5 × 20), 100 feet.



The air-way 10 feet square would have a perimeter of section 4 × 10 = 40 feet, while the other would have a perimeter of (20 + 20 + 5 + 5) 50 feet, compared with only 40 in the former; so that for equal lengths the friction of the air would only be 40 in the square air-way compared with 50 in the oblong one; and the friction in 50 yards of length in the square-shaped air-way would be no more than that in 40 yards of length in the oblong one for the same quantity of air. Since the air in a mine presses with nearly the same force upon every square foot, it is quite natural that the frictional resistance should be greater or less in amount, to the same extent that the rubbing surface or number of square feet exposed to the air is greater or less; and this is the general law or principle that has just been stated and illustrated by examples.

The pressures employed to ventilate mines are commonly reckoned at so much per square foot of area, and not by the entire pressure employed, which is equal to the number of square feet multiplied by the pressure on each square foot of sectional area in the shaft or air-way. For instance, a ventilating pressure of 10 lbs. to the square foot on an air-way 100 feet in area is equal, on the whole, to $10 \times 100 = 1{,}000$ lbs. If the same pressure of 10 lbs. per foot is applied to an air-way of only 50 feet area, the total pressure is only $10 \times 50 = 500$ lbs.; owing to the area being one-half, the total or gross pressure is also only one-half. In order to get the same total pressure, we must make the pressure per foot greater in the same proportion that the area is less, when the rubbing surface and *velocity* of the air are to be the same in two cases. If we reckoned ventilating pressure by its total amount, we would not require to notice this law, it is so self-evident; and it is only because we speak and treat of it as so much pressure per *square foot* that we require to consider the number of square feet to which it is applied. If there were two air-ways, one just twice the area of the other, the *velocity of the air* and *the extent of rubbing surface* being the same in each, then we must apply twice the pressure to each square foot of the small one that is required by the larger one, to overcome the equal amount of friction in the two airways, the quantity of air passing in the smaller one being just one-half of that in the larger. As an example, if we had an





air-way 10 feet by 10 feet the area would be 100 feet, and the perimeter of section 40 feet; and another air-way 5 feet high by 15 feet wide, the area would be 75 square feet, or just 3-4ths of the area of the former; the perimeter of section would be, however, exactly 40 feet in both airways. In the larger air-way we would only require to employ 3-4ths of the pressure on each foot of surface (that is to say, 3-4ths of the water gauge) that we would require to employ on each foot of the smaller area, so as to make up the same total ventilating pressure—the rubbing surface for an equal length of airway being the same in the two cases, because the perimeter of their sections are equal, and the velocity of the air being taken as the same in the two cases, the quantities of air per minute would be simply proportional to their respective areas under these circumstances.

This second law relating to the friction of air in mines need not have been noticed at all if we had reckoned ventilating pressure as a whole; but as we generally speak of it as so many pounds per foot, we must also take into account, as has previously been remarked, the number of square feet to which it is applied—that is, the area of the section of the airway—in the same manner that the area in inches of the cylinder or piston of a steam engine multiplied by the pressure on each square inch gives the total force applied to the piston. An inch of water-column, as shown by a water-gauge, represents a pressure of about 5.2 lbs. per square foot.

The third general law relating to the friction of air in mines is, that the pressure required to overcome the friction in the same air-ways *varies* (that is to say, increases or decreases) in the same proportions that the *square* of the velocity of the air increases or decreases; so that a double velocity of air, in the same air-way, meets with a *double double*, or four-fold resistance; a treble velocity meets with a *treble treble*, or nine-fold resistance; and a velocity of four times as great gives rise to a resistance four times four, or sixteen times as great. In the same way a half velocity meets with one-half of a half, or 1-4th of the resistance; 1-3d of the velocity encounters only a third part of a third, or 1-9th of the friction, and so on.

The third law of friction, at first sight, looks rather complex. Consideration, however, shows it to be quite natural, because, if we double the velocity of the air in the same air-way, we, in the first place, cause twice the quantity of air to meet the resistance in a given time; and, in addition to this, every part of this double quantity meets every resistance with a double velocity or momentum; the double quantity of air and the double velocity taken together, may well be supposed to give rise to a *double double*, or four-fold resistance; and this is the true law. Again, if we treble the velocity of the air, we thereby cause three times the number of particles to meet the resistance in each moment of time, and this alone should treble the resistances; but, in addition to this, the treble quantity meets the resistances with three times the speed or momentum, which *trebles the threefold* resistance that arises from the threefold number of particles of air that meet the resistances each moment of time; on the whole making a ninefold resistance for a threefold quantity of air in a given time.

The laws of ventilation would be very simple, quite as simple, indeed, as they are natural, were it not that, in lieu of the mere quantity of air circulating in a given time, or the mere velocity of the air, we must make use of the square of the quantity, or, what is the same, the square of the velocity, in our calculations;

and, as a matter of course, in calculations for comparative results, if we employ the squares of the quantities or velocities, we must expect, as results, not the quantities or the velocities simply, but their squares, and therefore it will be necessary to extract the square roots of the results so obtained in order to get at the simple quantities themselves.

It has already been stated that there is one other principle bearing on the friction of air passing through mines, to the effect that it is greater or less in the same proportion that the density or weight of each cubic foot of air is greater or less; so that if each cubic foot of air had a double weight it would have a double amount of friction; or, if it had only half the weight, it would have only half the amount of friction in the same air-way, when the velocity or the number of cubic feet per minute is the same; but the variations in the density of the air in mines are so very small, compared with the whole density, that the effects of this law on the amount of ventilation are very small—so small, indeed, as to be practically unfelt, at any rate as an increase or reduction of friction in the moving air; even in an upright or vertical shaft the density of the air would only be altered, on the average, by about 1-60th part of its amount, compared with a level air-way, supposing the shaft to be 150 fathoms deep, so far as the pressure of the atmosphere is concerned. The changes of density arising from the heat of upcast shafts, in expanding the air, have a greater effect, so far as such shafts alone are concerned, under furnace ventilation; but this does not affect the friction of the air in the workings of the mine; and, even in these shafts, the lessened density, arising from expansion by heat, has its effects on reducing the shaft friction greatly modified, by the greater velocity due to the increase in the volume of the air; this increased velocity does more than make up, by the accompanying increase of friction, for any reduction in such friction that is due to the lessened density of the air in every case; the friction, in fact, increases or decreases in just the same proportion that the volume of a given weight of air increases or decreases, whether the change of density arises from change of temperature or from change of pressure. Supposing the temperature of the air in a mine to be 60° in winter and 65° in summer, on the average, such a change would only alter the friction in such mine by about 1-104th of its amount. In summer the friction would be 1-104th greater than in winter for the same weight of air, but it would, at the same time, be about 1-104th part less for the same volume of air—an alteration hardly worth notice for the present purpose. The total friction or the total pressure due to the friction of air rubbing against the top, bottom, and sides of the air-ways of mines is not very well ascertained; and all the experiments, at least all that have come under my notice as having been made for the purpose, have been in some respects of a rude character, the necessary particulars not being given in the accounts published to fix with rigid accuracy its amount.

From the best accounts of such trials, it seems probable that for every foot of rubbing surface, and for a velocity in the air of 1,000 feet per minute, the friction is equal to 0.26881 feet of air column of the same density as the flowing air, which is equal to a pressure, with air at 32°, of 0.0217 lbs. per square foot of area of section; calling this the *co-efficient of friction*, we have the rules on the opposite page with respect to the friction of air in mines. Putting these formulæ into words, we have the following set of rules:

(1.) *To find the total pressure* due to friction.*—Multiply the co-efficient of friction by the extent of the rubbing surface, and the product by the square of the velocity in thousands of feet per minute; that is to say, by the square of the

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* The *total pressure*, in these rules, is found by multiplying the sectional area of the air-way, in feet, by the pressure per square foot.

Total pressure.......... $pa = ksv^2$ (1)

Rubbing surface........ $s = \frac{pa}{kv^2}$ (2)

Velocity squared........ $v^2 = \frac{pa}{ks}$ (3)

Co-efficient of friction.... $k = \frac{pa}{sv^2}$ (4)

Pressure per foot........ $p = \frac{ksv^2}{a}$ (5)

Area of section......... $a = \frac{ksv^2}{p}$ (6)

Where $p =$ pressure per sq. foot,
$a =$ sq. feet of sectional area.

$s =$ the area of rubbing surface exposed to the air.

$v =$ the velocity of the air in thousands of feet per minute —1,000 feet per minute being taken as the unit of velocity.

$k =$ the co-efficient of friction in the same terms or unit as p is taken in.

quotient resulting from dividing the velocity in feet per minute by 1,000.

(2.) *To find the rubbing surface.*—Divide the total pressure by the product of the co-efficient of friction and the square of the velocity in thousands of feet per minute.

(3.) *To find the velocity.*—Divide the total pressure by the product of the co-efficient of friction and the rubbing surface; this gives the square of the velocity, the square root of which is the velocity itself, in thousands of feet per minute; this multiplied by 1,000 will give the velocity in feet per minute.

(4.) *To find the co-efficient of friction from experiments.*—Divide the total pressure by the rubbing surface and the square of the velocity (in thousands of feet per minute) multiplied together.

(5.) *To find the pressure on each foot of section.*—Multiply the co-efficient of friction, the rubbing surface, and the square of the velocity (in thousands of feet per minute) all into each other, and divide the product by the area of the section.

(6.) *To find the area of the section.*—Multiply the co-efficient of friction, the rubbing surface, and the square of the velocity (in thousands of feet per minute) all into each other, and divide by the pressure on each foot of sectional area.*

The foregoing rules embrace only the pressure due to friction, and not that due to the creation of velocity, so that they may be regarded as being true of long pipes and air-ways, as they are given, but as requiring an allowance for the pressure due to the velocity in short pipes and air-ways. This allowance renders the rules much less simple.

Now, these rules, which are found out

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* If it is preferred to employ in these rules the velocity in feet per minute, in lieu of in *thousands* of feet per minute, the co-efficient of friction, in lieu of .26881, would become .00000026881; and if the velocity is taken in feet per second, it would become .000967716.

by practical trials or experiments, lead us to many very important conclusions in reference to the best mode of conducting the ventilation of mines, in proof of which it would be easy to multiply examples.

These laws of friction may be illustrated by the following example:

In an air-way 10 feet square = 100 feet area, and 25,000 feet, or nearly five miles long, if the velocity of the air were 1 foot per second, or 60 feet per minute, the quantity of air would be 6,000 feet per minute—the pressure due to friction (taking the pressure at 14.7 lbs. per square inch, and the temperature at 32°) would be .7812 lbs. per square foot of sectional area of the air-way, the horse-power being .142.

In another air-way of equal length, but instead of being 10 feet square only five feet square, giving only 25 feet or 1-4th of the area of the larger air-way, we have the following results: The rubbing surface in the small air-way would only be one-half of that in the large one; but, on the other hand, the area to which the ventilating pressure would apply would only be 1-4th; and at the same time the velocity of an equal volume of air would be increased fourfold in the lesser air-way; this increase of velocity alone making sixteen times the friction, so that on the whole it would be thirty-two times as great; making the pressure on each square foot 24.998 lbs., being thirty-two times as great as in the large air-way. And therefore, on the whole, the *power* expended would be also thirty-two times as great in the small as in the large air-way, for the same amount of ventilation per minute: the coals consumed would also be thirty-two times as great. If furnace ventilation were used, and the heat of the upcast shaft and pressure per foot were the same, instead of 6,000 cubic feet per minute, as in the large air-way, we should only have 1,061 feet in the smaller one; but, in this case, the coals burnt would only be $\frac{1}{\sqrt{32}}$, or between 1-5th and 1-6th of the former quantity, and the power would be less in the same proportion, for the lesser quantity of air. This shows in a striking manner the great advantage of large air-ways.

The calculations relative to the two cases, compared with each other for the example just given, stand thus:

FOR THE LARGE AIR-WAY.

The length is 25,000 feet, and the perimeter of section is $4 \times 10 = 40$ feet; so that the rubbing surface

$s = 40 \times 25,000 = 1,000,000$ sq. ft.
the area $a = 10 \times 10 = 100$ square feet,

the velocity $v = \frac{60}{1,000} = .06$, in thousands of feet per min.;

and $k = .26881$, being the co-efficient of resistance in feet of air-column of the same density as the flowing air.

Now by formula (5) we have

$$p = \frac{k\,s\,v^2}{a}$$

giving in this case

$$p = \frac{.26881 \times 1{,}000{,}000 \times (.06 \times .06)}{100}$$

$$= 9.67716$$

feet of air-column as the pressure required.

Taking the flowing air to have had the density due to a temperature of 32°, and to a pressure of 14.7 lbs. per square inch, a cubic foot of it would weigh .080728 lbs., and, therefore, such a column would represent a pressure of

$$9.67716 \times .080728 = .7812 \text{ lbs. per sq. ft.};$$

and hence the horse-power due to the friction of 6,000 cubic feet of air per minute, in passing through such an air-way would be

$$\frac{6{,}000 \times .7812}{33{,}000} = .142, \text{ or about 1-7th of a}$$

horse-power.

FOR THE SMALL AIR-WAY.

Proceeding as in the former case, we have

$$\frac{.26881 \times (20 \times 25{,}000) \times (.24 \times .24)}{25}$$

$= 309.66912$

feet of air-column as the pressure required for putting the same quantity of air, 6,000 cubic feet per minute, into circulation; being equal to a pressure of $309.66912 \times .080728 = 24.9989$ lbs. per square ft.; giving

$$\frac{6{,}000 \times 24.9989}{33{,}000} = 4.545 \text{ horse-power.}$$

If the *pressure per square foot* was the same in the small as in the large air-way, or .7812 lbs. per square foot, the air-column would be $\frac{.7812}{.080728} = 9.67716$ feet high;

and the square of the velocity (in thousands of feet per minute) would by formula (3) be

$$v^2 = \frac{9.67716 \times 25}{.26881 \times (20 \times 25{,}000)} = .0018$$

and hence the simple velocity, in thousands of feet per minute, would be

$$v = \sqrt{.0018} = .042426,$$

and the velocity in feet per minute would therefore be

$$.042426 \times 1{,}000 = 42.426;$$

and this gives for the quantity of air that would be put into circulation in the small air-way, by the same pressure per foot that is required to circulate 6,000 cubic feet per minute in the large one,

$42.426 \times 25 = 1{,}061$ cubic feet per minute, as has been stated.

To circulate 1,061 cubic feet of air per minute in the small air-way would, however, only involve the application of

$$\frac{1{,}061 \times .7812}{33{,}000} = .0251 \text{ horse-power},$$

which, under the conditions of the small air-way, and the assumed pressure, represents the entire power due to the friction of the quantity of air that would circulate in it.

Air, in being heated under a constant pressure, expands 1-459th part of its volume at the temperature of zero of Fahrenheit's thermometer for each degree of temperature imparted to it; 459 cubic feet of air at 0° become 469 at 10°, 479 at 20°, 489 at 30°, and so on. 1,000 cubic feet of air at 32°, the temperature of melting ice, expand to 1,366½ cubic feet, at 212°, the temperature of boiling water. To find the relative volumes occupied by equal weights of air, under equal pressures, but at different temperatures, we have simply to add the constant number 459 to the temperatures, and the sums give the relative volumes. The ordinary pressure of the atmosphere is equal to that of a column of water about 34 feet or 400 inches in height; we, however, seldom employ a difference of more than 2 or 3 inches of water column as ventilating pressure in mines. The pressure of the air is about 2,116 lbs. per square foot, but we seldom employ more than 10 to 17 lbs. extra as ventilating pressure. Owing to the ventilating pressures being so small, the changes of density in the air of mines (as it circulates), arising from changes of temperature, the mixture of watery vapor or steam, the gases given off, and one or two other causes, give rise to small local pressures in the various splits of air in a mine. In rise splits these local pressures usually operate against the general ventilating pressure, and lessen the quantity of air that would otherwise circulate. In dip splits these small local pressures commonly act in the same direction as the general ventilating pressures, and so add to the amount of their ventilation. This arises from the return air of any split being generally less dense than the intake air.

The laws of ventilation lead us to conclude that if we increase or decrease the total ventilating pressure, and total quantity of air circulating in a given time, where the seam of coal is perfectly level, each way or split will get a *fixed share* of the whole of the air entering the mine, no matter how long or short may be the different splits, and no matter how great or small may be the quantity of air. This is contrary to an old notion, that a short split gets an increasing and a long one a decreasing share of any lessened amount of ventilation, apart from considerations as to the rise or dip of the seam. Not long ago this point was severely tested, by numerous experiments, at several collieries; the results showed that the old idea was a mistaken one, and that the only changes that took place in the *proportion or share* of air going to different splits, with a reduced ventilation, arose from their relative rise or dip, together with the relative densities of the intakes and returns, and had no connection with the mere lengths of the splits. In ordinary cases, where the air of the returns is less dense than that of the intakes, if we have a short level split regulated so that, with the full ventilating pressure, it gets the same amount of air as a long dip split, and if we then halve the total quantity of air circulating, we find that the short level split no longer gets its share, but only a quantity less than that which goes into the long dip split; the very reverse of this is the case where the long split is a rise one; and these results are perfectly agreeable to the laws of ventilation that have been stated. In practice, and with the ordinary splits of air used in mines, except in extreme conditions as to the amount of rise and dip, and changes of density in the air, and in the amount of ventilation, the *share or proportion* of air going into the different splits of a mine is nearly maintained, whether we increase or lessen the total amount of ventilation; and any deviation from this depends upon the rise or dip of the splits, and not at all upon their relative lengths. In practice, then, when any reduction of ventilation has been brought about, we should generally find that the rise splits have been more affected than dip ones, if even the rise splits are shorter than the dip ones, and we should therefore expect to find accumulation of gas in the short rise splits rather than in the long dip splits of the mine. The greater the rise the greater is the danger of this, quite apart from the mere length of the splits, supposing them to be equally well ventilated to begin with.

So far as experiments have gone, they

show that if we had a series of equal sized and similarly shaped air-ways, made of different substances, the friction of air in passing through them would differ according to the nature of the substances.

Taking the friction in earthenware pipes at	100
In the air-ways of mines it would also be.	100
In sheet-iron pipes, new and clean	39
In " " rusty inside	10
In cast-iron pipes, sooty inside	20
In " " tarred inside	18
In tin pipes the friction would only be	10

So that 1-10th of the pressure would send the same quantity of air through a tin pipe that would be required to force that quantity of air through an earthenware pipe of the same size in the same time. (See opposite page.)

From these laws we learn, that the quantity of air that will pass through any mine is greater or less as the ventilating pressure is greater or less, but not in the same proportion. When the air-ways are the same, the quantity of air only alters in the proportion of the square root

Table showing the values of the co-efficient of friction, represented by the letter k, in the formulæ given at page 21, being the height in feet of air column of the same density as the flowing air, required to overcome the frictional resistance encountered by 1,000 cubic feet of air per minute in passing through a passage having one foot of sectional area, and presenting one square foot of rubbing surface to the air in motion.

Nature of the material composing the pipe or air-way.	State of the internal or rubbing surface exposed to the wind.	Observers' names.	General temperature of the air or gas.	Head of column of the same density as the moving air or gas required to overcome the friction; being the co-efficient of friction $=k$.	Remarks.
Burnt earth	Clean	Peclet	Hot	0.26881	In applying these values of k to the formulæ at page 21 since they are calculated for velocities of which the unit is 1,000 feet per minute, the real velocities in feet per minute must be divided by 1,000, to give the value of v in the formulæ; and v in the formulæ must be multiplied by 1,000 to give the velocity in feet per minute.
Galleries of a coal-mine	Ordinary state	G. C. Greenwell	Cool	0.25436	
Sheet-iron	New and clean	Peclet	Hot	From 0.10583 to 0.06773	
Cast-iron ?	Ordinary ?	Mons. Rudler Peclet	Hot	0.08466	
Cast-iron	Sooty		Hot	0.05292	
Cast-iron	Old, tarred	Girard	Cool	0.04844	
Gas in pipes } cast-iron	Ordinary	Mr. Hawkesley	Cool	0.03014	
Water in pipes } cast-iron	Ordinary	Eytelwein	Cool	0.03028	
Sheet-iron	Old and rusty	Girard	Cool	0.02752	
Tinned iron	?	D'Aubuisson	Cool	0.02540	

of the pressure; so that a fourfold pressure only gives a double quantity of air, and a ninefold pressure only gives a treble quantity of air. But, on the other hand, one-fourth of the pressure still gives one-half of the air, and one-ninth of the pressure gives one-third of the air. The changes in the quantity of air, then, are sluggish as compared with the changes in the ventilating *pressure*, only varying as its square root. The quantity of air, however, is more sluggish still in reference to the *power* employed to cause it to circulate. The quantity of air only varies as the cube root of the power, and of the quantity of coals burnt to produce it; so that eight times the coals only double, and twenty-seven times the coals only treble the quantity of air circulating in a mine, whether the ventilation is produced by furnace action, ventilating machines, or otherwise, so long as the air-ways remain in the same unaltered state. From this we learn, that we must not expect any great general improvement in the ventilation of mines from a mere increase of power; any increase in the quantity of air in the same air-ways is slow, small, and costly, compared with the necessary increase of power required to produce it.

In the same manner these general laws show us, that the quantity of air increases as we decrease or lessen the extent of the frictional rubbing surface; but again, not in the same proportion, but only as the square root of the extent of the rubbing surface. If we could do away with three parts out of four of the rubbing surface, so as to reduce it to 1-4th, other things being the same, we should only double the quantity of air in the mine; if the rubbing surface were reduced to even 1-9th, the quantity of air circulating per minute would only be increased to three times its previous amount. On the other hand, if the extent of workings and rubbing surface were increased to four times, or nine times their previous amount, while the area of the air-ways and the ventilating pressure remained unaltered, the air would only be lessened to one-half or one-third of its previous amounts respectively by such extensions, if we suppose the size of the air-ways and the number of splits of air to remain the same, as well as the ventilating pressure, in each case.

From these laws, then, we learn, that either to increase the ventilating pressure, or to lessen the extent of rubbing surface exposed to the air circulating in mines, is a very slow and very costly mode of proceeding to increase the amount of ventilation, as the quantity of air circulating in a given time alters so slowly with any alteration that may be made in the ventilating power or pressure, or in the mere extent of rubbing surfaces that may be presented to it. For general improvements we must, therefore, look chiefly in some other direction, owing to these being slow and costly modes of increasing the ventilation of a mine.

The same general laws of resistance show us that if we could reduce the velocity of the air, consistently with increasing the quantity circulating in a minute, we should greatly lessen the friction in comparison with the quantity of air circulating, and so obtain an increased quantity for the same amount of friction, or by the same ventilating pressure. This object is accomplished by splitting the air, so that instead of allowing the whole of the air to traverse the whole of the workings, a separate portion is taken into each different district of workings, and also brought out in a separate channel to a point near the up-cast shaft, after it has done its work. The air, as a whole, thus has as many ways to go in, and as many to come out by, as there are separate splits in the mine; the extent of the rubbing surface is not lessened by this, on the whole, but the area offered to the air is greatly multiplied; and although the velocity of each current may be reduced, still, on the whole, the quantity of air in all the splits is very much greater than if there were only one single current in the mine, even when the ventilating pressure is the same. Splitting the air does not necessarily enlarge the area offered to the air in the shafts, and the increased resistance arising from the increased quantity and velocity of air in them sets a limit to the benefits resulting from splitting the air in a mine. Owing to the resistance offered by the shafts, we dare not have more than a limited number of splits in a mine, because although every split adds to the total quantity of air circulating, still in each separate split the quantity ultimately becomes less and less, and if the number be too great, the current of each becomes too feeble and slow to sweep into the holes, corners, and places driven in advance of the actual current; and besides this, powder smoke is a long time in being carried away from the workmen. Still it is a fact that an additional quantity of air, on the whole, is obtained from every new split that is made.

The following general rules should be observed in splitting the air in mines:

Every principal split of air should commence as near as possible to the bottom of the downcast shaft, and should have a distinct air-way to return in, as nearly as may be, to the furnace or the bottom of the upcast shaft, except in cases where it is necessary to mix different currents, lest some one or more of them may be dangerously charged with gas. Splits of air only commencing far into the workings of a mine have comparatively little effect in increasing the quantity of air.

Where the air-ways are nearly of the same area in all parts of a mine, and the gases given off and the workmen employed are pretty evenly distributed, the length of the runs of the different splits should be as nearly equal to each other as circumstances may permit. The observance of this rule has a tendency to render regulators and other obstructions comparatively needless, and so to increase the amount of ventilation.

If we have a number of splits of air in a mine, each with an equal amount of air, then it is necessary so to obstruct each of the shorter splits as to cause their frictional resistances, when they have their proper share of air, to be as great as that of the longest split, when it also has its due share; otherwise they would get too much air, and the longer ones too little. These obstructions, of course, lessen the total quantity of air circulating.

The increased quantity of air obtained by splitting depends greatly upon the relative depths and areas of the shafts, as compared with the lengths and areas of the air-ways forming the workings of the mine. Supposing a mine to have such shafts and air-ways that when there are five equal splits of air the shaft resistances amount to one-half of the resistances offered by the mine—and this is no uncommon case—then, if before splitting the air at all we had a ventilation of 10,000 cubic feet of air per minute, the following are the quantities of air that would circulate by increasing the number of equal splits, while the entire extent of the workings, and the upcast shaft, and the ventilating pressure all remained the same:

No. of Currents.	Quantities of Air on the whole.	Quantities in each split.
1	10,000	10,000
2	27,892	13,946
3	49,449	16,480
4	71,527	17,882
5	90,789	18,158
6	107,800	17,966
10	141,710	14,171

In this case the coals burnt, whether in a furnace or by an engine driving a ventilating machine, would increase in the same proportion that the quantity of air increased, because the power would increase in that ratio. If the coals burnt, and the power remained unaltered, the results would only be as follows:

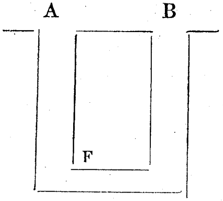
No. of Currents.	Total Quantities of Air per minute.	Quantities of Air per minute in each split.
1	10,000	10,000
2	19,813	9,906
3	29,022	9,674
4	37,121	9,280
5	43,736	8,747
6	48,797	8,133
10	58,556	5,856

Enlarging the sectional area or size of air-ways has a great effect in increasing the ventilation, but it is attended with great cost, and in general terms may be said to be much less effectual than judiciously splitting the air into a series of different currents. The beneficial effects of splitting air are, I believe, more fully appreciated, and the practice is more extensively followed in the Newcastle coal-field than in any other mining district; but even there it too often happens that the splits are made too far from the bottom of the downcast shaft, and are again brought into the same return too soon after they leave the face of the workings. This often arises from pillars being worked away near the shafts, without proper places being left to make additional air-ways leading to and from the more distant parts of the mine. This a very common oversight, and often entails either danger or a serious outlay, which might be avoided by care and forethought.

ON THE MEANS OF APPLYING POWER OR PRESSURE TO PRODUCE VENTILATION.

We have seen that *pressure* is required to put air into motion, and more particularly, to overcome the friction it meets with in rubbing against the top, bottom, and sides of the galleries in mines. We have next to consider the means employed to give rise to this ventilating pressure. There is constantly a pressure of nearly a ton to the square foot in every direction in the air near the surface of the earth, owing to the weight of the air above it; and we must either increase or lessen the amount of this pressure, in order to put the air into motion; and it is only the amount of this increase or decrease, and not the entire pressure, that puts the air into motion and overcomes the friction in mines.

Take the case of two pits or shafts, of equal depth, and having their tops and bottoms on the same level, and filled with stagnant air, which likewise occupies an opening, extending from the bottom of one shaft to the bottom of the other; and suppose that in the first place the weight of the air in one shaft is the same as that in the other, the temperature and other conditions being the same in each, and that the shafts are of the same sectional area or size: in this state the two columns of air exactly counterbalance and support each other, so that there is no motion in the air, and therefore no ventilation is produced; nay, further, if one shaft be ever so much larger than the



other, the air it contains can only press upon that in the smaller one over the area of the smaller section; the air contained in the extra size of the larger shaft resting or pressing upon the sides of the shaft or air-way at the place where the area is lessened, and not upon the air in the smaller shaft; so that whatever may be the relative sizes of the shafts, the air in the one will balance that in the other if the density of the air is the same in each; this may be termed the pneumatic paradox. If, however, by means of a furnace, at F in the diagram, the air in one shaft is heated and expanded, it becomes lighter, bulk for bulk, than the cool air in the other, and no longer balances it; the pressure of the heavier air then overcomes that of the lighter air, and pushes it up the shaft before it, while the cool air from the cool shaft takes its place, but not in a cool state, as it gets heated in its turn in passing over the furnace, so that there is a continual current of cool air going down one shaft which pushes before it a constant current of hot air up the other shaft.

In mines, the air, instead of being allowed to go direct from the bottom of one shaft to the furnace and up the other, is guided by means of stoppings and doors into and along the various passages forming the workings of the mine, before it is brought upon the furnace or into the upcast shaft, and, by this means, a continual stream of air is made to sweep through the workings and mix with and carry off the gases as they are given off, and this is called the ventilation of the mine.

In some cases, men, boys, and horses require to travel in directions that the air is not wanted to go, and in such cases we cannot build up the way by stopping, but have to place doors to stop the passage of the air; in many cases, the opening of a door to allow a person or horse to pass would have a bad effect by allowing the air to pass through it even for so short a time, and to avoid this evil two doors are employed, so that one may be always closed when the other is open. The use of doors in the principal roads of mines is objectionable where it can be avoided, and is much less common, at least in some districts, than formerly; in other districts of the kingdom the number of ventilating doors is very great, notwithstanding the danger and cost attending their use. The neglect of keeping doors shut has, no doubt, often led to serious explosions of gas in mines. In some cases it is necessary that the route of one split or current of air should intersect and cross that of another, and in such cases one current is carried over or under the other by means of drifts or masonry to prevent their coming into contact with each other; this arrangement is called an air-crossing or bridge. When an explosion occurs, the force of the concussion often destroys air-crossings, and thereby interrupts the ventilation; so that they should be avoided as far as possible, and made very strong where they are used in fiery mines.

It has already been stated that where there are several splits of air in a mine, of different lengths, and offering different resistances, we sometimes find that too little air goes into the longer splits, compared with the quantity going into the shorter ones; and in order to correct this evil, we put regulators or contractors into the shorter ones so as to increase the natural resistance they offer, and cause more air to go into the long splits. Regulators, although useful where they are unavoidable, are not desirable, as they contract the air-ways, and so lessen the total quantity of air circulating in the mine in a given time. As far as may be, the routes of the air should be so proportioned that each split may obtain its proper share of air without using any artificial regulators. Doors, air-crossings, and regulators should be avoided in all cases where the circumstances of the mine admit of it.

In order to find the amount of ventilating pressure, and the power arising from the use of a ventilating furnace, we require to know the weight of a cubic foot of air at different temperatures and under different pressures. Careful experiments show that 459 cubic feet of air at 0°, or zero of Fahrenheit, the common thermometer, weigh 39.76 lbs., when the pressure is 30 inches of mercury of the density due to 32°; a pressure equal to nearly 14¾ lbs. per square inch, which is the ordinary pressure of the atmosphere —but it only weighs 1-30th of this, or 1.3253 lbs., when the pressure is only one inch of mercury; and since 459 feet of air at 0° expand exactly a cubic foot for each degree of heat added, we get the following *rule* to find the weight of a cubic foot of air, at any temperature, and under any pressure:

$$W = \frac{1.3253 \times I}{459 + t};$$

where I = the height in inches indicated by the barometer, and t = the temperature by Fahrenheit's thermometer. At 38°, under a pressure of 30 inches of mercury, 100 cubic feet of air weigh just 8 lbs.; a box 5 feet every way would just contain 10 lbs. of such air.

On one occasion, at Hetton Colliery, when 225,176 cubic feet of air per minute were circulating, the average temperature of the air in the downcast shaft was 43½°, and that of the air in the upcast shaft was 211°. Now, by the rule given (if we take the barometer half-way down the shaft to have shown a pressure of 30½ inches of mercury), the weight of a cubic foot of air, taking the average, in the downcast shaft, would be .08044 lbs.; and the pit being 900 feet deep, this air would produce a pressure of .08044 × 900 = 72.396 lbs. on each square foot by its mere weight. The air in the upcast shaft, owing to its being hotter, would be lighter, and only produce a pressure on each foot = 54.297 lbs.; and hence the difference of pressure on each square foot of area, between the two columns of air, would be = 18.099 lbs. Now in order to find the horse-power producing ventilation, we require to multiply this difference of pressure of 18.099 lbs. on the square foot, by the number of cubic feet of air circulating per minute, and then to divide the result by 33,000, the number of lbs. raised one foot high per minute by a horse-power. In this case then, we find the ventilating power at Hetton Colliery must have been

$$\frac{\overset{\text{lbs.}}{18.099} \times \overset{\text{c. ft. pr. min.}}{225,176}}{33,000} = 123\tfrac{1}{2} \text{ horse-power;}$$

225,176 cubic feet of air per minute being in circulation at the time. Some part of the extra heat of the air in the upcast over that in the downcast shaft, would have arisen from the heat of the mine, and would have caused what is called a natural ventilation, even if furnaces had not been used. But natural ventilation is generally very small in amount, and cannot be depended upon, as, in hot weather, the downcast column of air is little or no cooler or denser than the air in the upcast, and, by making the weight or pressure of the two air columns equal, there is a liability to stop all ventilation.

Where furnaces are used to produce ventilation, the deeper the upcast shaft the better; because this gives rise to a longer upright column of hot air, and so causes a greater ventilating pressure, and consequently a brisker ventilation. Furnaces are not well suited for causing ventilation in shallow pits, for this reason; and sometimes machines are fixed at the top of the pit to pump the air through the mine. These machines, for the most part, exhaust air out of the upcast shaft, and the pressure of the denser air in the other, or downcast shaft, causes the current. Such a ventilating machine, like a furnace, acts by rendering the upcast column of air lighter, bulk for bulk, than the air in the downcast shaft; the same effect is sometimes produced by large fans, the machines mostly being worked by steam engines. A few of these ventilating machines are used in the south of England, and in Wales, and a great number are used on the Continent. Ventilating machines of the best construction consume less coals (to produce the same quantity of ventilation) than furnaces, except in very deep and dry shafts. But coals are plentiful at collieries, and the liability of ventilation being suspended by the breakage of the machinery, and the inconveniences attending the stopping of the ventilating machine for repairs to itself or the engine, together with the difficulty of applying ventilating machines to working shafts, render them, in the opinion of many persons, less to be depended upon than furnaces in general. Taking the average of eleven different collieries in the Newcastle district, each pound of coal puts 13,000 feet of air into circulation, by the action of furnaces. In some collieries two or three times as much air is circulated by each pound of coal as in others, depending on the depth of shaft, and its state as to dryness or wetness, and on the friction of the air in the shafts and in the mine itself. There are in Wales some seven or eight ventilating machines at work, producing ventilations varying from 16,000 to 75,000 cubic feet of air per minute. The largest machine is one recently erected at Deep Duffryn Colliery, which, with air-ways of sufficient area, is capable of producing a ventilation of double the latter quantity.

Jets of steam were proposed to produce the circulation of air in mines a few years ago, but by an elaborate series of experiments their effects were found to be far below that of furnaces, and the cost to be very great; the idea of their utility for ventilating mines was therefore abandoned. The useful work contained in a jet of steam probably varies as the cube of the velocity of the steam, so that if the same quantity of water was converted into steam, in a given time, the power contained in it would depend upon the smallness of the jet orifice it had to escape through; by halving the area of the jets we should obtain eight times the power, and should therefore get a double quantity of air through the same mine; by reducing the area of the jets to one-third, we should obtain a treble quantity of air, by the same quantity of steam, in a given time. At least these are the results given by calculations made upon the principles of mechanics, which are found to be true for streams of water and air. I have not taken pains to compare them with the results of the experiments on steam jets as applied to ventilation, because the results seemed to hold out no hope of steam jets ever being made available for ordinary ventilation. There are, no doubt, temporary and peculiar circumstances under which steam jets may be useful in the production of ventilation, such as cases where it is either unsafe or impracticable to use ordinary furnace action.

Falls of water are sometimes employed in downcast shafts to cause a current of air to descend; but as the water has, for the most part, to be raised again from the mine, and as the effects they produce are small, in proportion to the power employed, this mode of ventilation is seldom used, except where furnace action or other means are necessarily excluded.

OF THE INSTRUMENTS USED IN CONNECTION WITH THE VENTILATION OF MINES.

Barometer.—The pressure of the atmosphere in different states of the weather varies from 28½ to 31 inches of mercurial column, being from 2,016 to 2,192 lbs. per square foot; and it is found that the natural discharge of gas in mines becomes greater as this pressure becomes less, so that the reduced atmospheric pressure, as shown by a barometer, is a warning that an increased quantity of gas may be expected to be given off in mines, and, therefore, calls for increased care and vigilance to keep the ventilation at its greatest point, and for taking precautions against the enemy. The air pent up in goaves and abandoned excavations also expands in volume from the reduction of pressure which causes the fall of the barometer; the increased volume being given out into the air-ways, and often being mixed with gases necessitating careful attention, as the barometrical pressure of the atmosphere is lessened; the more suddenly the pressure falls the more observable are these results. A very *sudden* fall of the mercury is accompanied by a worse effect on mines than a greater fall, provided it takes place less rapidly. An increase or decrease of the pressure of the atmosphere has little or no effect in altering the *volume* of air passing through a mine in a given time, although it alters the *density* and *weight* of such air often to a considerable extent.

A good portable barometer may be used to ascertain the friction of air in passing along air-ways, because the loss of pressure, by friction, as the air circulates, is always taken off the pressure of the air itself; so that in level air-ways the air is less and less compressed as we proceed in the direction followed by the air, and the reduction of pressure is an exact measure, in such air-ways, of the pressure spent on friction.

When the air-way rises or dips, allowances for this have to be made in finding the amount of friction from the pressure of air in this manner. Aneroid barometers appear to be better suited for use in mines than the common barometer or weather glass, as they are more portable, less liable to derangements, and almost equally reliable, at least for comparative indications, which are just as useful as absolute ones in mines.

Thermometer.—The thermometer is used to measure the heat of air in mines; when the fresh air, going down a downcast shaft, is heated, it expands and becomes lighter, and is therefore less able to force the air before it through the mine; in other words, by being heated, the weight of the column of air in the downcast shaft is reduced till it is more nearly equal to that in the upcast shaft, and consequently the ventilating pressure is lessened, and therefore the quantity of air circulating is also reduced in amount. By the use of this instrument we find the difference of temperature between the air in the downcast and that in the upcast shaft, and so are able to calculate the ventilating pressure due to the action of a furnace.

Water Gauge.—The water gauge is merely a glass tube, bent into the form of the letter U with a scale of inches and parts, by which we can measure the difference between the height of the water in one tube and that in the other. It has already been stated that the air loses the pressure that is spent on the friction as it progresses along an air-way. Now, when an air-way happens to turn so as to come nearly parallel to itself, there is often a door or stopping separating the two adjacent parts of the same air-way, and this instrument enables us, in a direct way, to measure the amount of pressure that is spent on friction between the two adjoining parts of the air-way so situated. The air has less pressure on the outcome or return side of the separation than the air on the intake side, which has not yet met with the friction of the intervening distance of air-way. If the water in one leg of the tube is exposed to the pressure of the intake air, while that in the other is exposed to the lesser pressure of the return air, the greater pressure on the intake leg of the water gauge sinks or depresses the surface of the water in that leg, and raises it in the other leg; the difference of level, which represents the ventilating pressure spent on the air-ways lying beyond the place where it is taken, is seldom so much as three inches, and often only one inch in well ventilated mines. The amount of water gauge can be increased, either by increasing the ventilating pressure, and consequently also the quantity of air circulating in a given time, while the air-ways are in the same state, or it can be increased by falls of material, or other obstructions in the air-ways, even while they lessen the quantity of air circulating; because such obstructions increase the frictional resistance of the air, and the gauge is a measure of that resistance. A water gauge does not show the shaft resistances when used in a mine; the pressure shown by the water gauge is equal to the general shaft ventilating pressure, *less* or *minus* the friction due to the air in the shafts and in the air-ways extending from the shafts to where the gauge is tried. It is also a measure of the resistances the air meets with in the workings lying beyond it, *less* or *minus* any local force, arising from the air in the returns being lighter than that in the intakes, in dip-ways; or it is equal to such friction added to any such pressure that may operate against ventilation from the same cause in the rise-ways or splits of air in the mine; and in cases where the air of the returns is more dense than that of the intakes, the effects arising from the dip or rise of the workings will, of course, operate in the reverse manner upon the indications of the gauge. When the air-ways remain in the same state, the amount of water gauge increases as the ventilation increases, and falls as it decreases; but the proportion of variation of the gauge-pressure is much greater than that of the quantity of air circulating; the *square* of the quantity of air, except in so far as local pressures may interfere, is proportional to the pressure indicated by the gauge, because the friction varies as the square of the quantity of air.

The *Anemometer* is an instrument used to measure the rate at which the air flies in mines. That invented by the late Mr. Biram is the one mostly used in English mines; it is not a very easy matter to find how much each of these instruments requires to be allowed for its own working friction; no perfect rule has yet been established for this purpose, although one is much needed. An approximate rule requires that a constant quantity should be added to the number of revolutions in a minute, no matter what may be the speed of the wind or of the instrument; and that the sum so obtained should be multiplied by another constant quantity, to give the velocity of the air in any terms in which we wish to find it. Coombes's anemometer can be put into or out of gear by pulling strings attached to it; this instrument is said to give very correct results, and is greatly used on the Continent; it is, however, more troublesome to use than Biram's anemometer, and is seldom seen in our mines. There are a few other kinds of anemometers; but a good and simple instrument, or mode for finding the velocity of air in motion, has probably yet to be contrived.

The Hygrometer.—In fine experiments, the hygrometer is used to ascertain the proportion of moisture in the atmosphere of mines, from whence its density and also its capacity for heat are found. Mason's wet and dry bulb hygrometer is better adapted for use in mines than the more delicate one of Daniel. The return air in nearly all mines is found to be saturated with vapor of water; that is to say, it contains the greatest quantity of vapor that can exist in it at its temperature; and a portion of vapor is condensed by the least degree of cooling that takes place in the air. An atmosphere saturated with vapor is lighter, bulk for bulk, than another at the same pressure and temperature, but containing less vapor.

In the discussion which followed—

Mr. Atkinson said: Supposing you have a long split and a short one in the same mine, and you regulate or contract the short one by an artificial obstruction until the quantity going into each is equal; then supposing, from some cause or other, the general ventilating pressure is gradually reduced: what would be the result? Would the short split get half of the remaining total quantity of air, or would it get less or more? That question would have been answered in my younger days by saying that the short split would ultimately take the whole of the air, and none would go to the long one. Now, however, it is a fact, which I have proved over and over again, that if the air-ways are level, and you reduce the ventilating pressure, each split will take its original *proportion ;* but if the long one is a dip-way and the short-way is a level one, on reducing the gross quantity of ventilation the long-way gets more than its original *share* of the reduced quantity, and so takes the lead of the short split. If, on the other hand, the long split is a rise and the short a level, on reducing the gross quantity the long split gets less and the short one gets more than its *share.* Supposing one split gets 60 per cent. and the other 40 per cent. of the total to begin with, if the airways are level, each will get the same percentage when the gross amount is lessened. Just the reverse results take place if you take the proportions from any standard amount of ventilation, and then *increase* the gross quantity, where there are rise and dip splits, supposing the air in the returns to be hotter and less dense than in the intakes in each case. If, however, the returns were so mixed with carbonic acid gas, and so cool as to be more dense than the air in the intakes, then the reverse results would ensue on increasing or reducing the ventilating pressure, where the splits are not level. We had a long discussion about this at the North of England Institute of Mining Engineers. Some one suggested, after the Lundhill accident, that instead of having air kept so much in one current, if they had taken it up each bank on separate splits, they would have got a much better ventilation; but the objection was raised that in the event of the furnaces being low and the general ventilation being reduced, the far-off places would get no air; it would all run through the "short cuts;" and it was to correct that idea that the matter was made the subject of investigation by careful experiments. Further, the benefit of splitting air depends in a great measure upon the proportion of resistance that occurs in the shafts as compared with that which occurs in the workings. The total pressure applied may be divided into two separate items, one of which is employed to overcome the shaft friction, and the other to overcome the resistance in the workings. Generally speaking, you can subdivide the workings till you reduce the friction very materially; but the friction in the shaft is, of course, always the same for a given quantity of air, and it is only from reducing the friction in the workings, that the beneficial results of splitting the air are derived. As to dumb drifts, in some collieries, where discharges of gas occur, it might be expedient to use them; but he would rather have sweeping ventilation, as a rule, and a mixing of the return air from the place where the gas was given off with that from the other ways, so as to render it safe before reaching the furnace. If you supply the furnace with fresh air, you never get with the same furnace the same amount of air into the workings, and our object is to cut down the amount of friction in the downcast and upcast shafts. There is one rare case where that does not hold, and that is if your returns were so charged with carbonic acid gas, so fearfully charged with it, that they would not let the furnace burn, you would have nothing else for it but to use fresh air, but you would use it at the expense of not getting the same amount of ventilation as you would get with ordinary air.

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